NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 269

AIR FORCE TESTS OF SPERRY MESSENGER MODEL WITH SIX SETS OF WINGS

By JAMES M. SHOEMAKER

UNITED STATES
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WASHINGTON
1927

AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	sec	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/sec		horsepower	HP.
Speed		km/hr		mi./hr	M. P. H.
		m/sec		ft./sec	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/sec.$^2=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} sec.^{2}) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from $c.\ g.$ to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/sec, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of $C.\ P.$ from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

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AIR FORCE TESTS OF SPERRY MESSENGER MODEL WITH SIX SETS OF WINGS

By James M. Shoemaker

SUMMARY

The purpose of this test was to compare six well-known airfoils, the R. A. F. 15, U. S. A. 5, U. S. A. 27, U. S. A. 35–B, Clark Y, and Göttingen 387, fitted to the Sperry Messenger model, at full scale Reynolds Number as obtained in the variable density wind tunnel of the National Advisory Committee for Aeronautics; and to determine the scale effect on the model equipped with all the details of the actual airplane. The results show a large decrease in minimum drag coefficient upon increasing the Reynolds Number from about one-twentieth scale to full scale. Maximum lift coefficient was increased with increasing scale for all the airfoils except the Göttingen 387, for which it was slightly decreased. A comparison is made between the results of these tests and those obtained from tests made in this tunnel on airfoils alone.

INTRODUCTION

This test was made to compare six well-known airfoils, the R. A. F. 15, U. S. A. 5, U. S. A. 27, U. S. A. 35–B, Clark Y, and Göttingen 387, fitted to the Sperry Messenger model, at full-scale Reynolds Number as obtained in the variable density wind tunnel of the National Advisory Committee for Aeronautics. The scale effect on the model equipped with all the details of the actual airplane was determined. Previous tests on this model conducted in the same tunnel have already been reported (Reference 1). The tests were made at the request of the Army Air Corps.

THE TEST

A one-tenth scale model, reproducing all the details of external construction which could be considered as contributing drag, was tested at tank pressures of one and of twenty atmospheres for the model equipped with each set of wings. By "tank pressure" is meant the pressure of the air within the steel shell of the tunnel. This is used as the simplest means of indicating the scale of the test. Thus a tank pressure of twenty atmospheres means that the Reynolds Number of the test is approximately twenty times as great as that of a one atmosphere test of the same model in this tunnel.

In addition, the model fitted with U. S. A. 5 wings was equipped with a propeller, made very accurately to scale, which was mounted on a bearing having little friction and allowed to turn as a windmill. This combination was tested at five tank pressures ranging from one to twenty atmospheres to determine the effect of the propeller.

A photograph and dimensioned drawing of the model will be found in Figures 1 and 2, respectively. The small streamlined object suspended beneath the fuselage in Figure 2 was used to represent the trailing-bomb type flight path recorder used in the flight tests of the airplane. Figure 3 is a photograph of the model in position for test. The fuselage is made of mahogany with metal fittings. The empennage is of brass and the wings are of dural, with steel struts. The dimensions of the biplane cellule are the same for all sets of wings. As will be seen from the drawing, the angle of incidence is $+2°$, while that of the stabilizer is $+1\frac{1}{2}°$. These angles were used for all sets of wings, the elevators remaining neutral.

A description of the tunnel and its balance mechanism will be found in Reference 2. The model was mounted in a manner similar to that used in the previous tests described in Reference 1. Two airplane streamline wires of sufficient stiffness to support the model were attached to

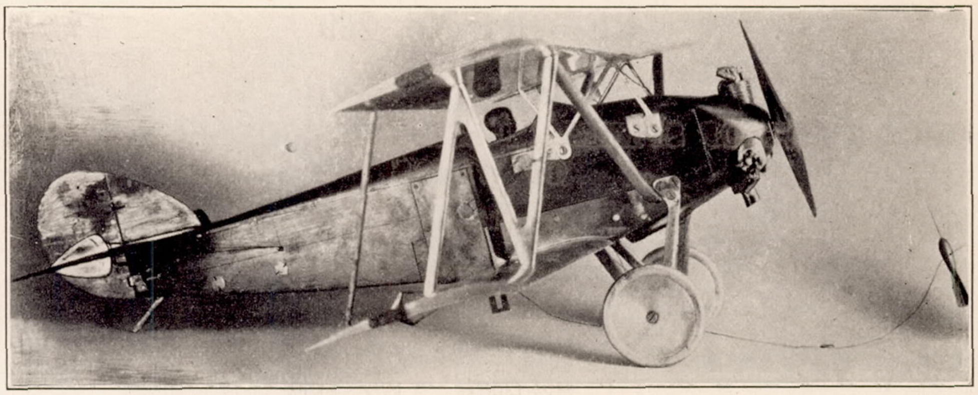

FIG. 1.—Model of Sperry Messenger airplane

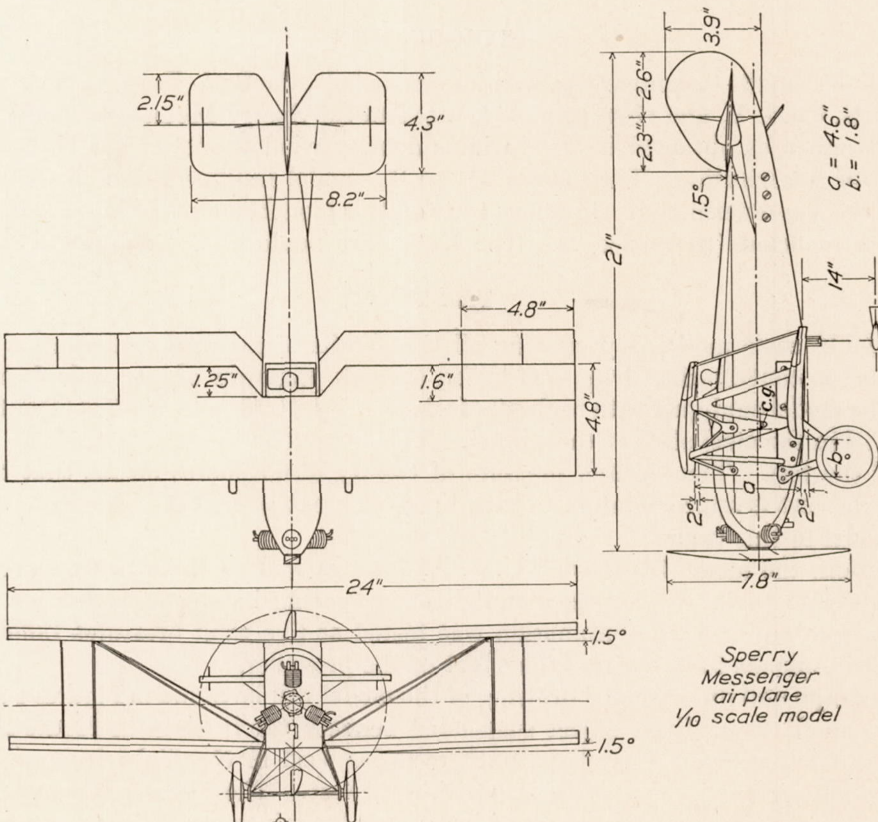

FIG. 2.—Plan, elevations, and dimensions of the Sperry Messenger model

the lower wing at the quarter-chord point and fixed at their lower end to the balance ring. A skid pivoting in the after part of the fuselage was attached to the vertical bar by which the angle of attack was changed. This set-up differed from that described in Reference 1 only in that faired shields were used over the streamline wires to within approximately 10 inches of the model to reduce the wire drag.

RESULTS AND DISCUSSION

The results of the tests, with drag coefficient and angle of attack corrected for tunnel-wall interference by the Prandtl formulas (Reference 3), will be found in Tables I to XVII. The

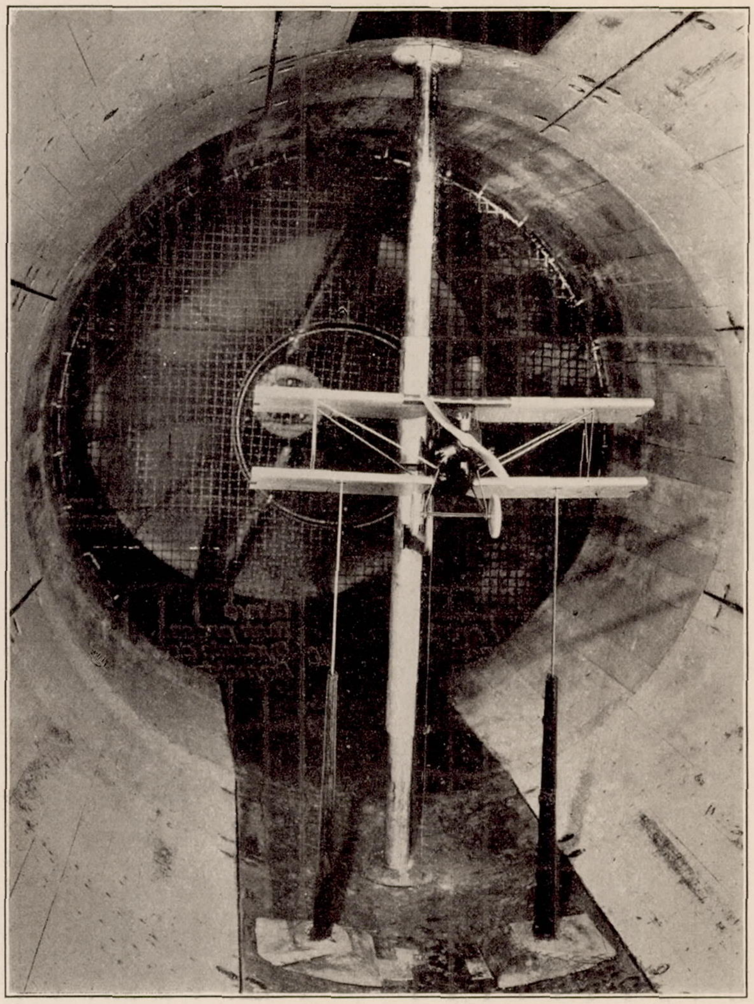

FIG. 3.—The model in the variable density wind tunnel

moment coefficients taken about the center of gravity of the airplane are given as measured. No correction for the effect of tunnel walls upon the moment was made.

The curves of C_D and C_M plotted against C_L as an ordinate are given in Figures 4 to 11. The value of the angles spotted on the polar curves is that measured in the tunnel and is not corrected for tunnel-wall effect. For the corresponding angles in free air, refer to the tabulated data. The curves for the model fitted with U. S. A. 5 wings and propeller are shown for five tank pressures in Figure 4. The spacing of these curves shows that the scale effect is large at the lower Reynolds Numbers, particularly that on minimum drag coefficient. There is very little difference between the drag coefficient at 10 and at 20 atmospheres. Figures 5 and 6 are from the 1 and 20 atmosphere tests, respectively, each showing the curves for the model with and without propeller. The ratio between minimum drag with and without propeller seems to

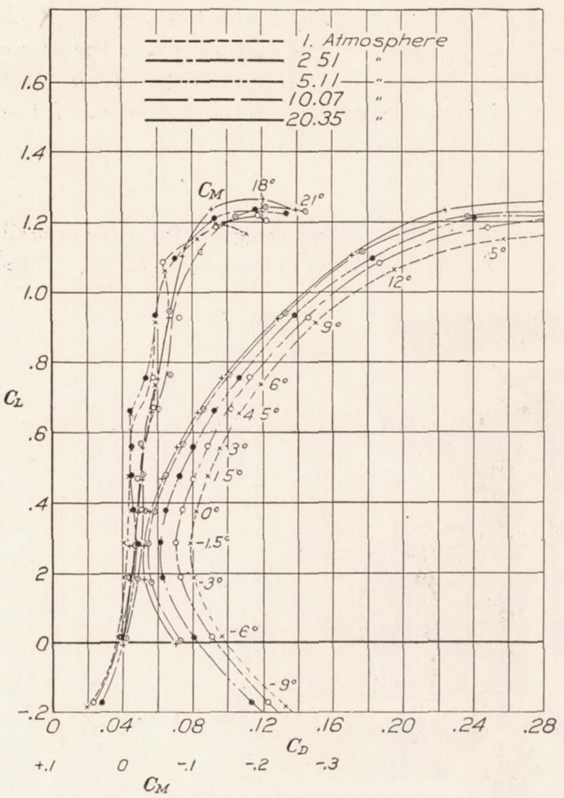

FIG. 4.—Polar curves of S. M. model with U. S. A. 5 wings and propeller

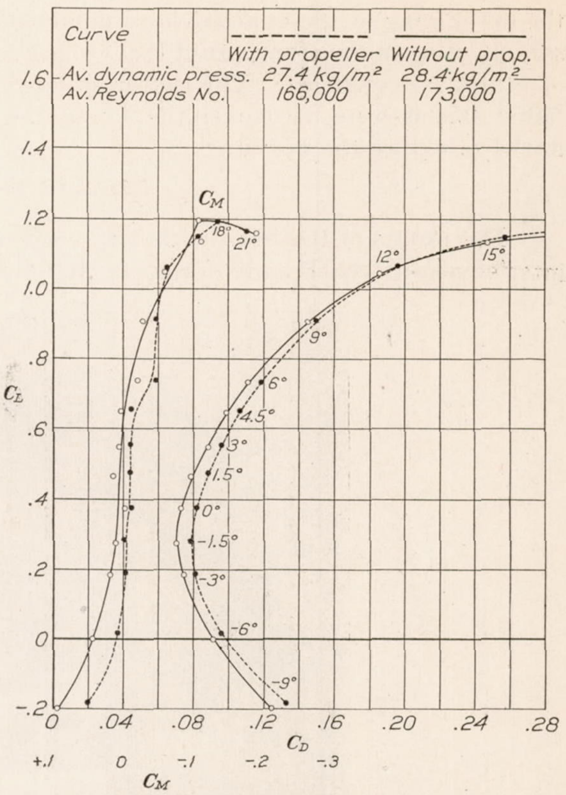

FIG. 5.—Polar curves of S. M. model with U. S. A. 5 wings at one atmosphere

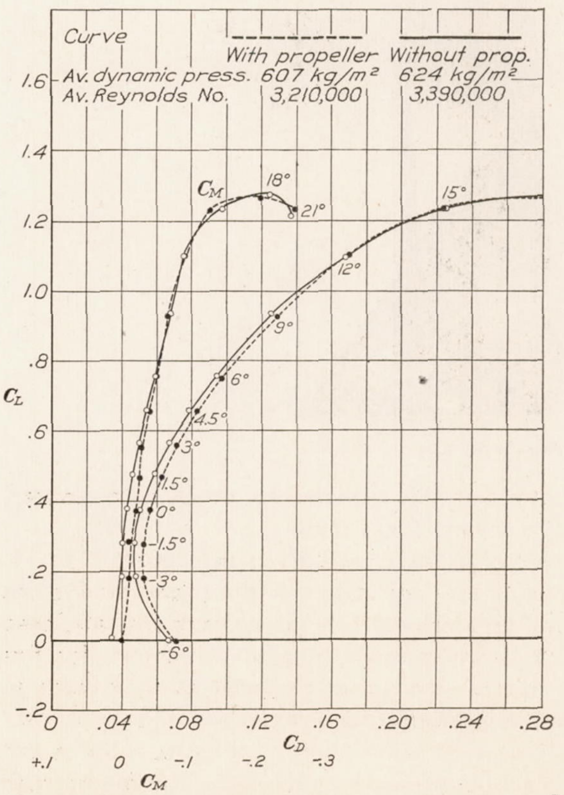

FIG. 6.—Polar curves of S. M. model with U. S. A. 5 wings at 20 atmospheres

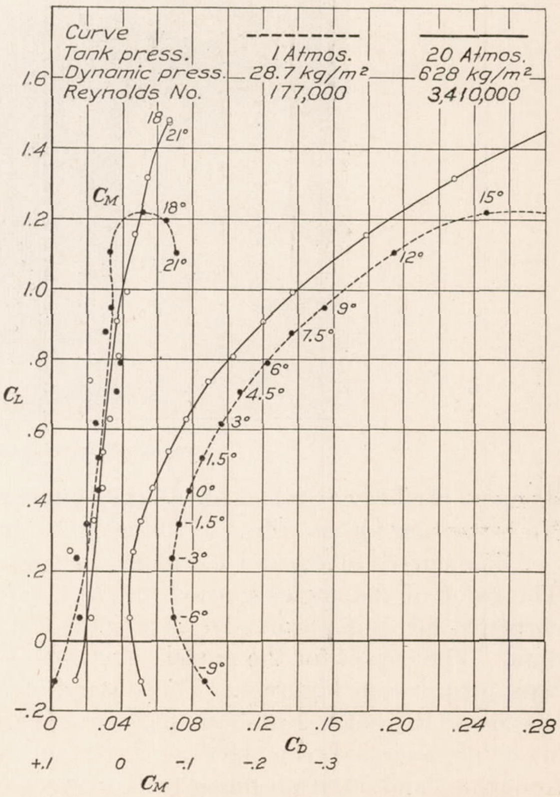

FIG. 7.—Polar curves of S. M. model with U. S. A. 35B wings and no propeller

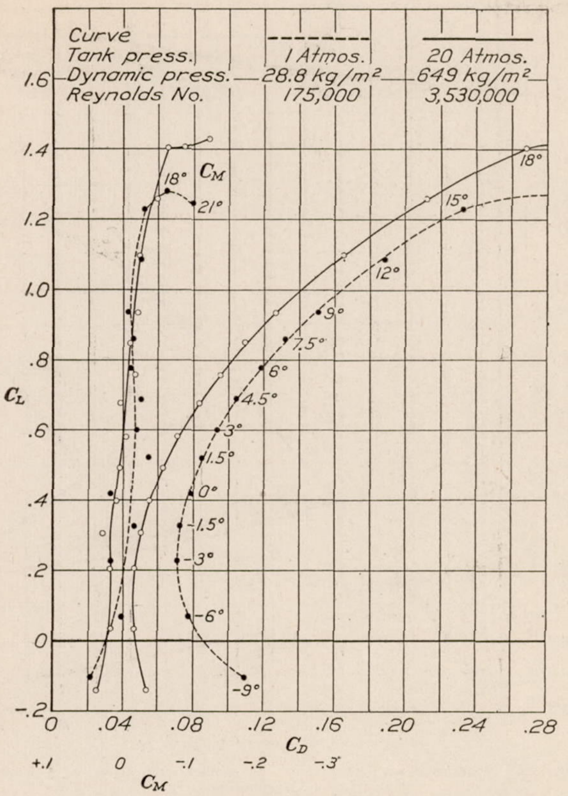

FIG. 8.—Polar curves of S. M. model with U. S. A. 27 wings and no propeller

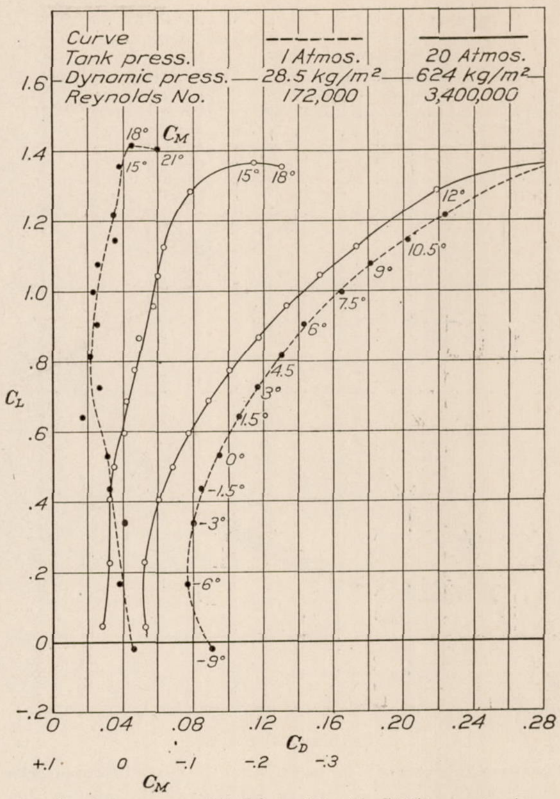

FIG. 9.—Polar curves of S. M. model with Göttingen 387 wings and no propeller

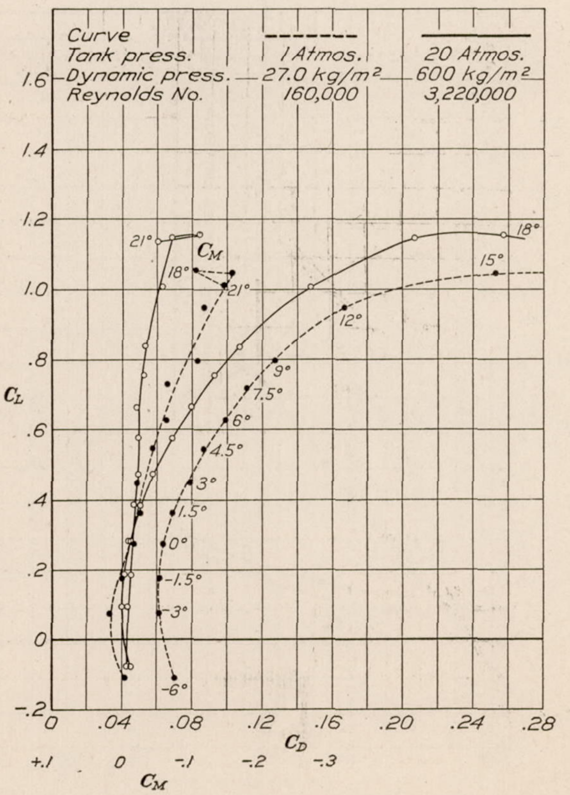

FIG. 10.—Polar curves of S. M. model with R. A. F. 15 wings and no propeller

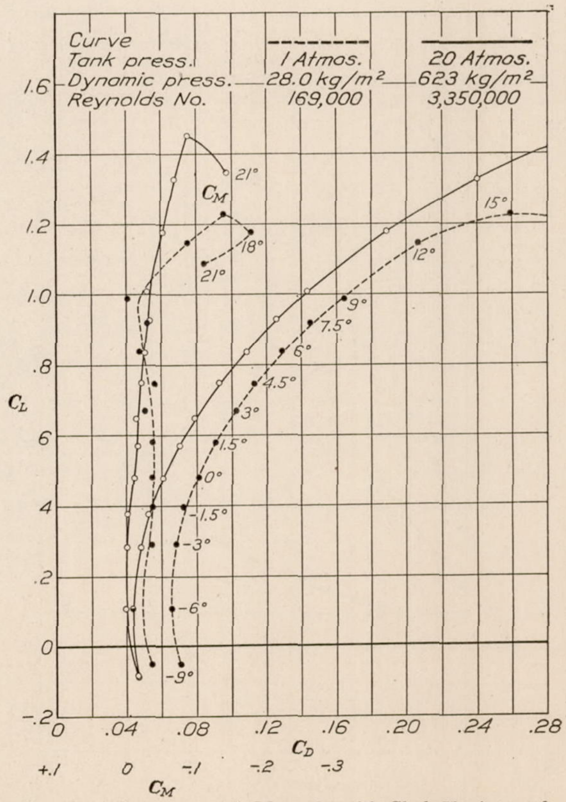

FIG. 11.—Polar curves of S. M. model with Clark Y wings and no propeller

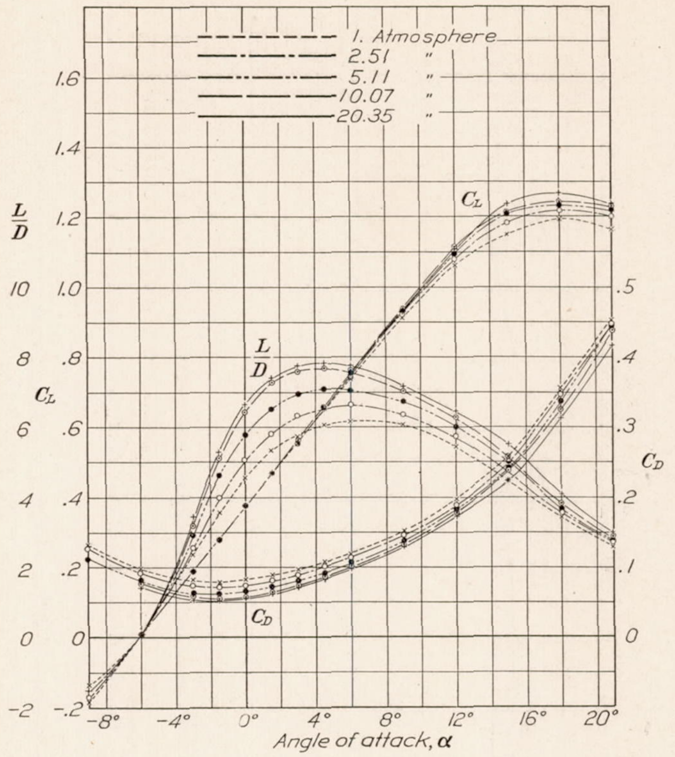

Fig. 12.—Characteristic curves of S. M. model with U. S. A. 5 wings and propeller

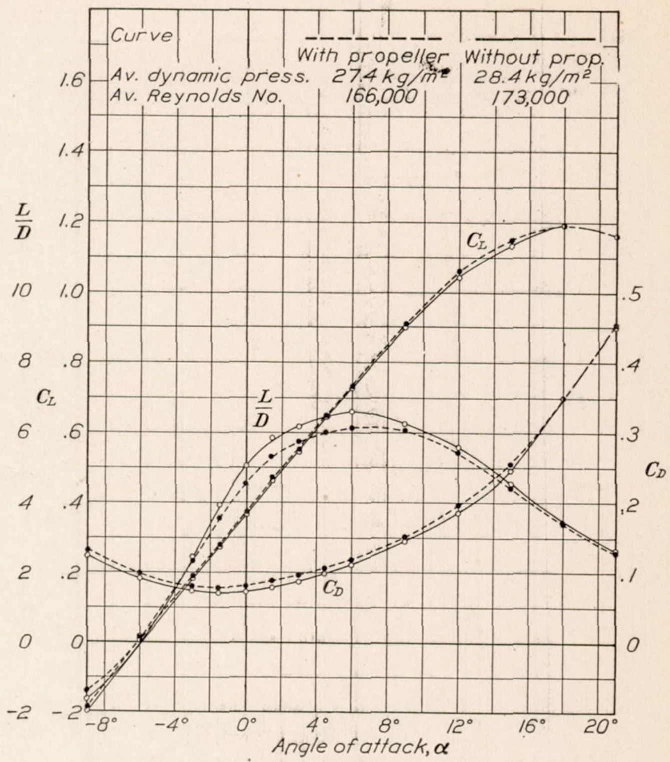

Fig. 13.—Characteristic curves of S. M. model with U. S. A. 5 wings at one atmosphere

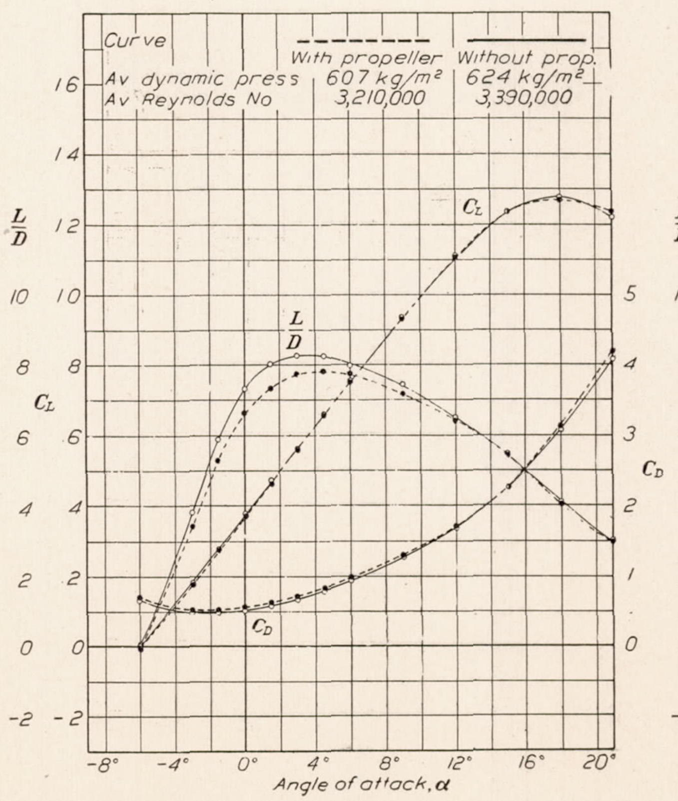

Fig. 14.—Characteristic curves of S. M. model with U. S. A. 5 wings at 20 atmospheres

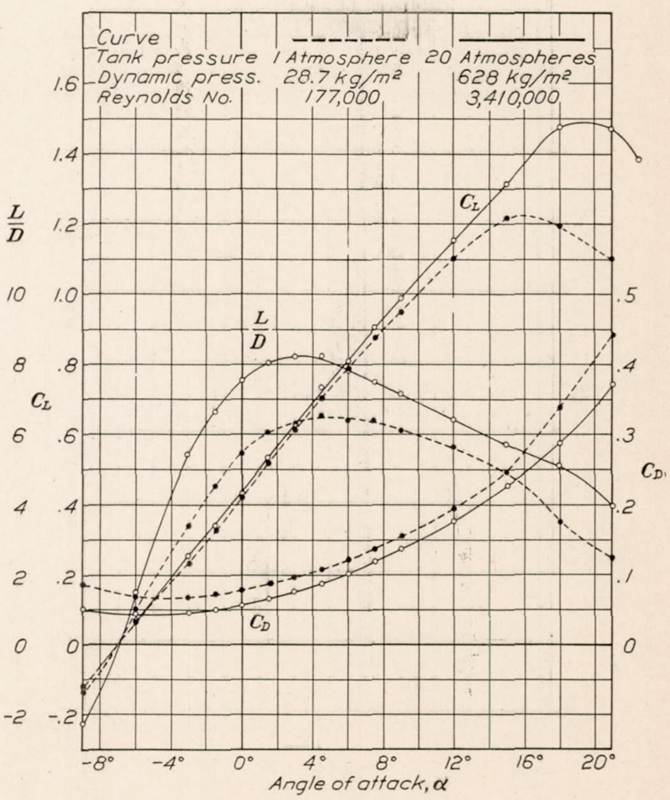

Fig. 15.—Characteristic curves of S. M. model with U. S. A. 35B wings and no propeller

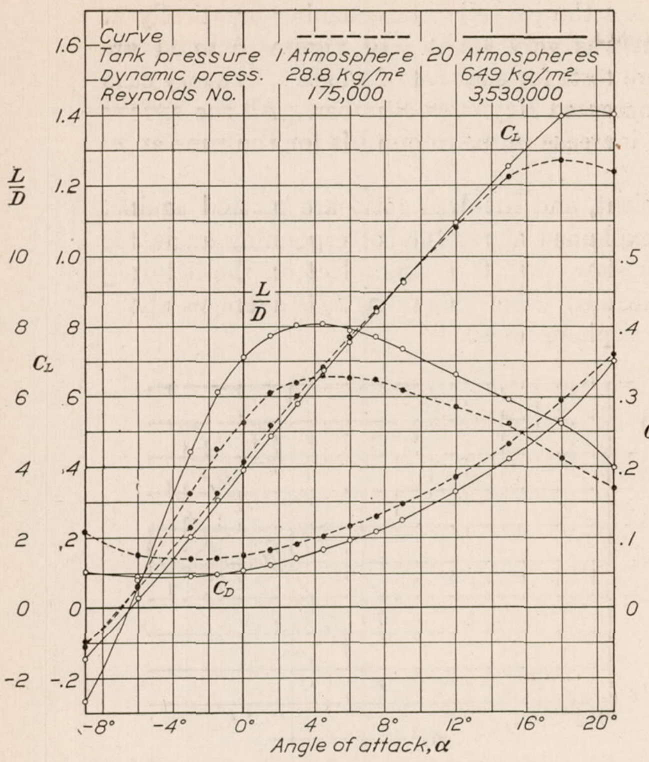

FIG. 16.—Characteristic curves of S. M. model with U. S. A. 27 wings and no propeller

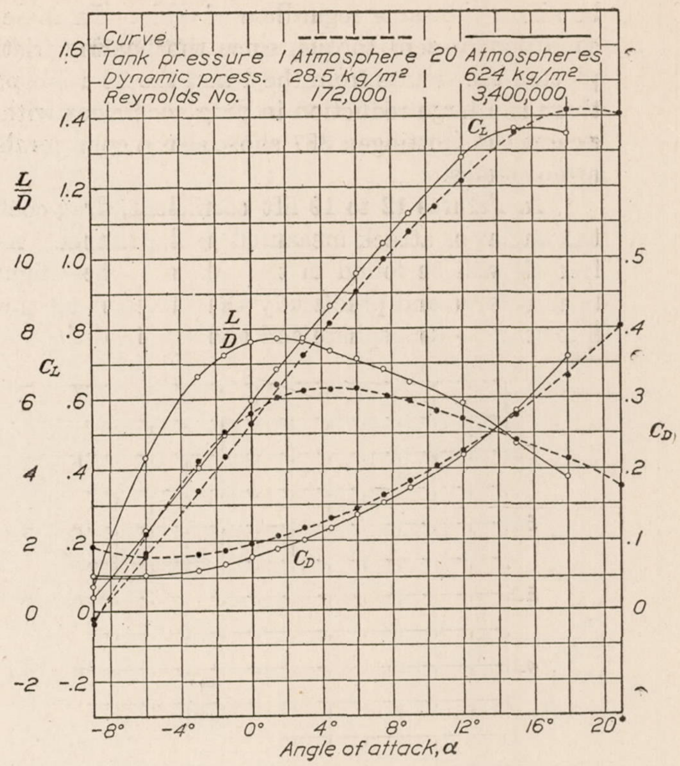

FIG. 17.—Characteristic curves of S. M. model with Göttingen 387 wings and no propeller

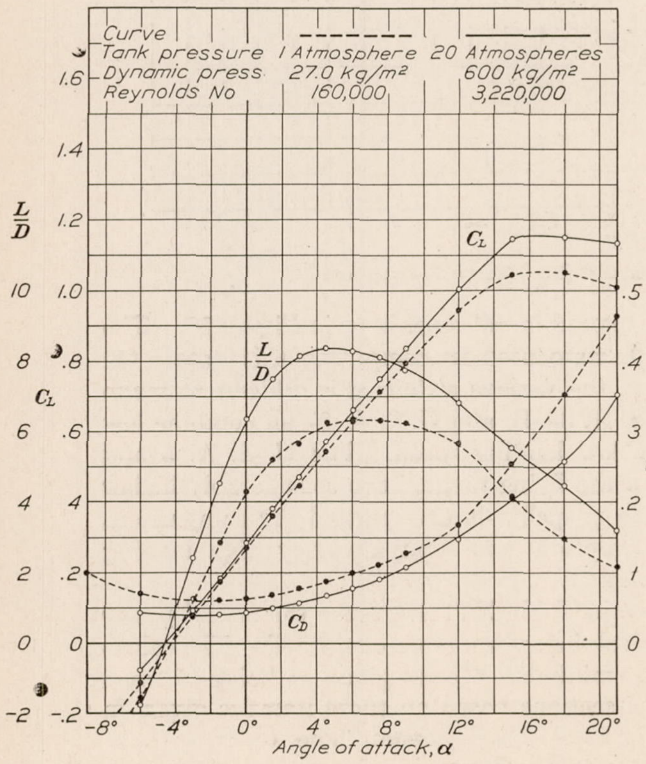

FIG. 18.—Characteristic curves of S. M. model with R. A. F. 15 wings and no propeller

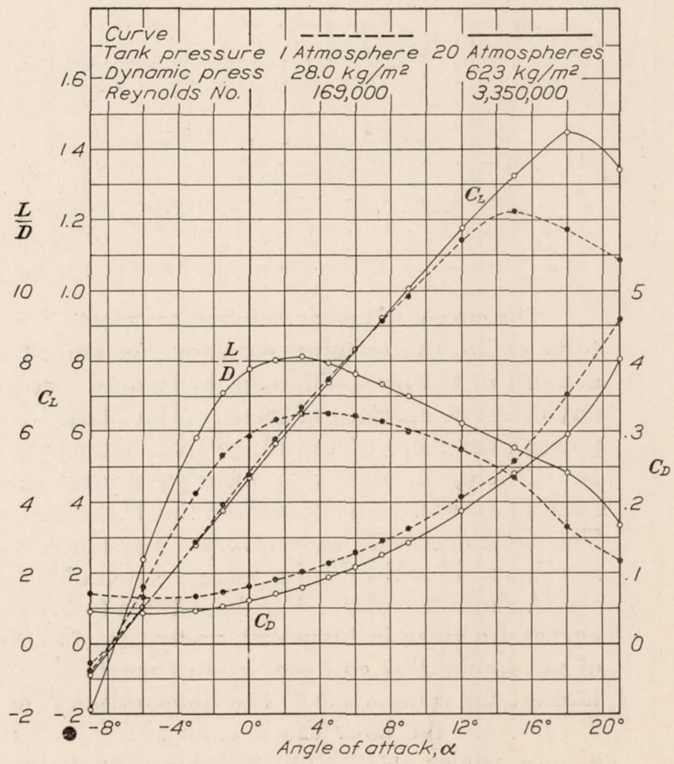

FIG. 19.—Characteristic curves of S. M. model with Clark Y wings and no propeller

be about the same regardless of scale. In these tests the propeller was running practically at condition of zero torque, since the bearing friction was very slight. In Figures 6 to 11 are plotted the results from the 1 and the 20 atmosphere tests for each set of wings. In every case there is a large reduction in drag coefficient with increased Reynolds Number. All the airfoils except the Göttingen 387 show also a considerable increase in maximum lift for the runs at 20 atmospheres.

In Figures 12 to 19 lift coefficient, drag coefficient, and lift-drag ratio are plotted against the angles of attack measured in the tunnel. As explained above the corresponding angles for free air will be found in the tables. These figures show that the scale effect on the lift-drag ratio is large and practically the same for all the airfoils. The maximum L/D averages about 8 for the 20-atmosphere and about 6.5 for the 1-atmosphere tests.

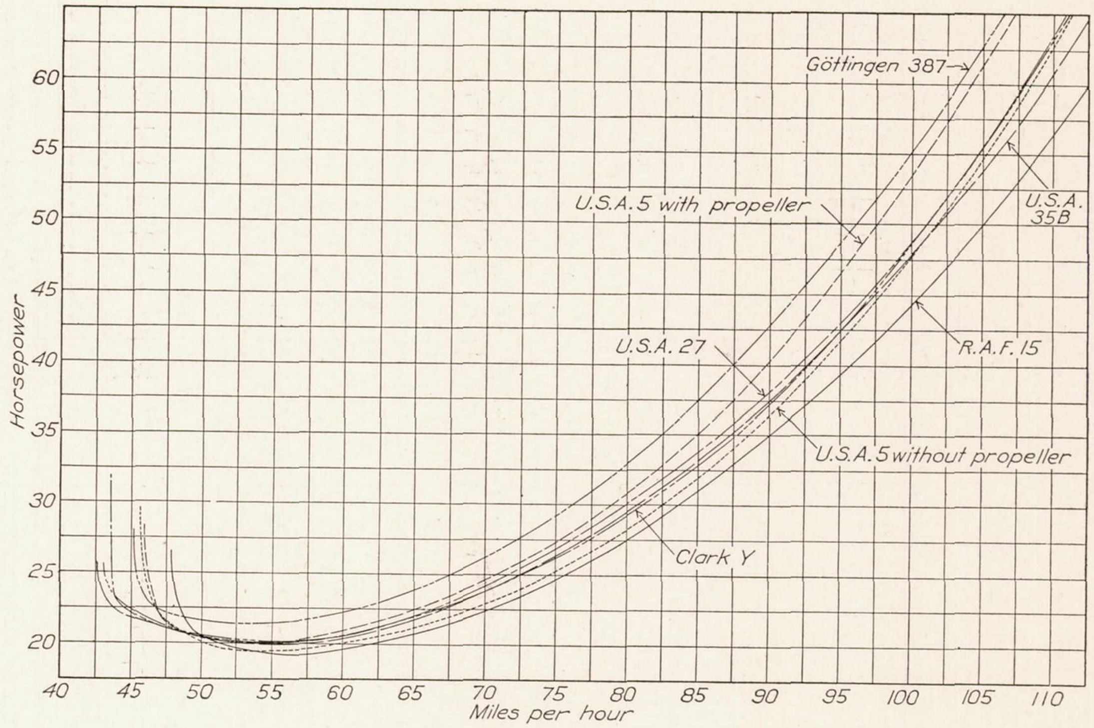

FIG. 20.—Curves of power required by Sperry Messenger airplane. Tests at 20 atmospheres

The curves of power required are plotted against speed in miles per hour in Figure 20. The tests at 20 atmospheres, corrected for tunnel wall, were used in computing this data. On account of the large difference in landing speed with the various airfoils it is difficult to make any direct comparison of merit. The Clark Y, U. S. A. 35–B, and U. S. A. 27 all combine low power over most of the range with comparatively low landing speed. The U. S. A. 5 and R. A. F. 15, while showing lower power over most of the flying range, have considerably higher landing speeds. The curve for the U. S. A. 5 with propeller is also plotted for comparison. The Göttingen 387 shows very large power consumption and comparatively high landing speed, and is evidently the poorest airfoil of the group.

A summary of the data from these tests is given in Table XVIII. Since the actual power curves are given in Figure 20, no figures of merit involving power were computed. The values of maximum L/D and the ratio of maximum C_L to minimum C_D are given as being of some interest for comparison. The order of merit of the sections based on these items is given in Table XIX for both the 1-atmosphere and the 20-atmosphere tests. The order for the airfoils alone, taken from variable density tunnel tests (Reference 4) are also given in this table. It will be seen that the order obtained from the 20-atmosphere airfoil tests is, with minor exceptions, the same as that from the 20-atmosphere Sperry model tests. On the other

hand, the one-atmosphere tests, both of airfoils and model, are very misleading when compared with the model tests at full-scale Reynolds Number.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *January 20, 1927.*

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2. Munk, Max M., and Miller, Elton W. The Variable Density Wind Tunnel of the National Advisory Committee for Aeronautics. N. A. C. A. Technical Report No. 227, 1926.

3. Prandtl, L. Application of Modern Hydrodynamics to Aeronautics. N. A. C. A. Technical Report No. 116, 1921.

4. Munk, Max M., and Miller, Elton W. The Aerodynamic Characteristics of Seven Frequently Used Wing Sections at Full Reynolds Number. N. A. C. A. Technical Report No. 233, 1926.

TABLE I

Sperry Messenger.
U. S. A. 5 wings without propeller.
Av. tank pres. = 1 atm.
Av. dynamic pres., q = 28.4 kg/m^2.
Av. Reynolds Number = 173,000.
Av. temperature = 24° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m^2.
Date, October 1, 1925.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−9	−0. 201	+0. 1245	−1. 61	+0. 094	−9. 11
−6	. 000	. 0913	0	. 043	−6. 00
−3	+. 184	. 0746	+2. 47	. 018	−2. 90
−1. 5	. 275	. 0702	3. 92	. 011	−1. 35
0	. 371	. 0735	5. 05	−. 004	+ . 20
+1. 5	. 463	. 0790	5. 86	+. 014	1. 75
3	. 546	. 0885	6. 17	. 005	3. 29
4. 5	. 648	. 0999	6. 49	. 000	4. 85
6	. 734	. 1110	6. 61	−. 022	6. 40
9	. 906	. 1455	6. 23	−. 030	9. 49
12	1. 046	. 1861	5. 62	−. 060	12. 56
15	1. 133	. 2476	4. 58	−. 113	15. 61
18	1. 194	. 3503	3. 41	−. 109	18. 64
21	1. 160	. 4568	2. 54	−. 190	21. 63

TABLE II

Sperry Messenger.
U. S. A. 5 wings without propeller.
Av. tank pres. = 20.3 atm.
Av. dynamic pres., q = 624 kg/m^2.
Av. Reynolds Number = 3,390,000.
Av. temperature = 39° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m^2.
Date, October 1, 1925.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−6	+0. 007	+0. 0662	+0. 11	+0. 014	−6
−3	. 184	. 0480	3. 83	. 000	−2. 90
−1. 5	. 280	. 0476	5. 88	−. 001	−1. 35
0	. 379	. 0518	7. 32	−. 008	+ . 20
+1. 5	. 475	. 0592	8. 02	−. 016	1. 76
3	. 563	. 0680	8. 28	−. 026	3. 30
4. 5	. 659	. 0796	8. 28	−. 036	4. 86
6	. 752	. 0941	7. 99	−. 049	6. 41
9	. 936	. 1260	7. 43	−. 071	9. 50
12	1. 100	. 1689	6. 52	−. 089	12. 59
15	1. 237	. 2261	5. 46	−. 145	15. 67
18	1. 279	. 3076	4. 16	−. 214	18. 69
21	1. 220	. 4093	2. 98	−. 244	21. 66

TABLE III

Sperry Messenger.
U. S. A. 5 wings with propeller.
Av. tank pres. = 1 atm.
Av. dynamic pres. $q=27.4$ kg/m².
Av. Reynolds Number = 166,000.
Av. temperature = 26° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m².
Date, October 5, 1925.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−9	−0. 184	+0. 1327	−1. 39	+0. 050	−9. 10
−6	+. 013	. 0962	+. 14	+. 007	−5. 99
−3	. 189	. 0804	2. 35	−. 004	−2. 90
−1. 5	. 282	. 0789	3. 57	−. 002	−1. 35
0	. 375	. 0827	4. 53	−. 013	+. 20
+1. 5	. 472	. 0886	5. 33	−. 011	1. 75
3	. 551	. 0960	5. 74	−. 013	3. 30
4. 5	. 652	. 1072	6. 08	−. 013	4. 85
6	. 737	. 1197	6. 16	−. 049	6. 40
9	. 911	. 1502	6. 07	−. 049	9. 49
12	1. 061	. 1955	5. 43	−. 064	12. 57
15	1. 150	. 2577	4. 46	−. 109	15. 62
18	1. 193	. 3511	3. 40	−. 135	18. 64
21	1. 161	. 4536	2. 56	−. 177	21. 63

TABLE IV

Sperry Messenger.
U. S. A. 5 wings with propeller.
Av. tank pres. = 2.51 atm.
Av. dynamic pres. $q=69.9$ kg/m².
Av. Reynolds Number = 417,000.
Av. temperature = 30° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m².
Date, October 5, 1925.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−9	−0. 171	+0. 1227	−1. 39	+0. 041	−9. 09
−6	+. 014	. 0916	+. 15	+. 005	−5. 99
−3	. 189	. 0737	2. 56	−. 010	−2. 90
−1. 5	. 283	. 0709	3. 99	−. 023	−1. 35
0	. 380	. 0748	5. 08	−. 029	+. 20
+1. 5	. 467	. 0804	5. 80	−. 022	1. 75
3	. 560	. 0884	6. 32	−. 029	3. 30
4. 5	. 664	. 1025	6. 48	−. 046	4. 86
6	. 753	. 1127	6. 68	−. 045	6. 41
9	. 929	. 1461	6. 36	−. 083	9. 50
12	1. 082	. 1871	5. 78	−. 059	12. 58
15	1. 183	. 2485	4. 76	−. 133	15. 64
18	1. 219	. 3463	3. 52	−. 195	18. 66
21	1. 201	. 4433	2. 71	−. 206	21. 65

TABLE V

Sperry Messenger.
U. S. A., 5 wings, with propeller.
Av. tank pres. = 5.11 atm.
Av. dynamic pres. $q = 148.2$ kg/m².
Av. Reynolds Number = 867,000.
Av. temperature = 29° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m².
Date, October 6, 1925.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−9	−0. 174	+0. 1138	−1. 53	+0. 030	−9. 09
−6	+. 007	. 0806	+. 09	−. 001	−6. 00
−3	. 187	. 0632	2. 96	−. 015	−2. 90
−1. 5	. 287	. 0620	4. 63	−. 023	−1. 35
0	. 379	. 0654	5. 80	−. 016	+. 20
+1. 5	. 473	. 0723	6. 54	−. 012	1. 75
3	. 558	. 0803	6. 95	−. 014	3. 30
4. 5	. 660	. 0929	7. 10	−. 012	4. 86
6	. 751	. 1064	7. 06	−. 035	6. 40
9	. 933	. 1385	6. 74	−. 048	9. 50
12	1. 098	. 1830	6. 00	−. 076	12. 59
15	1. 210	. 2406	5. 03	−. 132	15. 65
18	1. 232	. 3352	3. 67	−. 191	18. 66
21	1. 221	. 4471	2. 73	−. 235	21. 66

TABLE VI

Sperry Messenger.
U. S. A. 5 wings with propeller.
Av. tank pres. = 10.07 atm.
Av. dynamic pres. $q = 296$ kg/m².
Av. Reynolds Number = 1,670,000.
Av. temperature = 36° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m².
Date, October 6, 1925.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−6	+0. 007	+0. 0737	+0. 09	−0. 005	−6
−3	. 182	. 0569	3. 20	−. 021	−. 290
−1. 5	. 281	. 0550	5. 11	−. 020	−1. 35
0	. 376	. 0586	6. 42	−. 034	+. 20
+1. 5	. 479	. 0658	7. 28	−. 030	1. 76
3	. 564	. 0742	7. 60	−. 028	3. 30
4. 5	. 664	. 0865	7. 68	−. 055	4. 86
6	. 762	. 1016	7. 50	−. 070	6. 41
9	. 940	. 1335	7. 04	−. 069	9. 51
12	1. 115	. 1772	6. 29	−. 113	12. 60
15	1. 213	. 2371	5. 11	−. 162	15. 65
18	1. 243	. 3242	3. 83	−. 207	18. 67
21	1. 228	. 4351	2. 82	−. 263	21. 66

TABLE VII

Sperry Messenger.
U. S. A. 5 wings with propeller.
Av. tank pres. = 20.35 atm.
Av. dynamic pres. q = 607 kg/m².
Av. Reynolds Number = 3,210,000.
Av. temperature = 49° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m².
Date, October 6, 1925.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−6	−0.002	+0.0709	−0.03	−0.000	−6
−3	+.180	.0524	+3.43	−.011	−2.90
−1.5	.276	.0523	5.28	−.010	−1.35
0	.372	.0562	6.62	−.023	+.20
+1.5	.465	.0633	7.34	−.028	1.75
3	.556	.0719	7.73	−.029	3.30
4.5	.656	.0839	7.82	−.042	4.85
6	.751	.0971	7.74	−.051	6.40
9	.929	.1295	7.17	−.066	9.50
12	1.106	.1706	6.48	−.087	12.60
15	1.237	.2247	5.50	−.128	15.67
18	1.268	.3122	4.06	−.200	18.68
21	1.236	.4188	2.96	−.248	21.67

TABLE VIII

Sperry Messenger.
U. S. A. 35–B wings.
Av. tank pres. = 1 atm.
Av. dynamic pres. q = 28.7 kg/m².
Av. Reynolds Number = 177,000.
Av. temperature = 20° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m².
Date, April 13, 1926.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−9	−0.119	+0.0869	−1.37	+0.095	−9.06
−6	+.066	.0699	+.94	.059	−5.96
−3	.235	.0689	3.41	.064	−2.88
−1.5	.330	.0727	4.54	.049	−1.33
0	.426	.0781	5.46	.032	+.23
+1.5	.519	.0856	6.06	.034	1.78
3	.613	.0965	6.35	.036	3.33
4.5	.706	.1078	6.55	.007	4.87
6	.789	.1229	6.42	.001	6.42
7.5	.876	.1364	6.42	.024	7.97
9	.949	.1554	6.11	.014	9.51
12	1.105	.1950	5.66	.017	12.60
15	1.220	.2475	4.93	−.030	15.66
18	1.193	.3397	3.51	−.062	18.64
21	1.101	.4427	2.49	−.077	21.59

TABLE IX

Sperry Messenger.
U. S. A. 35-B wings.
Av. tank pres. = 20.2 atm.
Av. dynamic pres., q = 628 kg/m.^{2}
Av. Reynolds Number = 3,410,000.
Av. temperature = 38° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m.^{2}
Date, April 13, 1926.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−9	−0. 115	+0. 0512	−2. 25	+0. 066	−9. 06
−6	+. 066	. 0444	+1. 49	. 043	−5. 96
−3	. 254	. 0462	5. 50	. 073	−2. 86
−1. 5	. 340	. 0510	6. 66	. 038	−1. 32
0	. 433	. 0575	7. 53	. 026	+. 23
+1. 5	. 536	. 0665	8. 06	. 026	1. 79
3	. 629	. 0765	8. 22	. 017	3. 34
4. 5	. 737	. 0892	8. 26	. 045	4. 90
6	. 809	. 1034	7. 82	. 003	6. 44
7. 5	. 908	. 1202	7. 55	. 007	7. 99
9	. 991	. 1379	7. 18	−. 007	9. 53
12	1. 154	. 1785	6. 46	−. 019	12. 62
15	1. 317	. 2285	5. 76	−. 037	15. 71
18	1. 478	. 2889	5. 12	−. 067	18. 79
21	1. 472	. 3708	3. 97	−. 066	21. 79
22. 5	1. 384	----------	----------	----------	----------

TABLE X

Sperry Messenger.
U. S. A. 27 wings.
Av. tank pres. = 1 atm.
Av. dynamic pres., q = 28.8 kg/m.^{2}
Av. Reynolds Number = 175,000.
Av. temperature = 22° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m.^{2}
Date, April 16, 1926.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−9	−0. 104	+0. 1093	−0. 95	−0. 045	−9. 06
−6	+. 068	. 0777	+. 87	+. 001	−5. 96
−3	. 229	. 0711	3. 22	+. 017	−2. 88
−1. 5	. 328	. 0727	4. 51	−. 017	−1. 32
0	. 418	. 0788	5. 30	+. 017	+. 23
+1. 5	. 519	. 0846	6. 14	−. 036	1. 78
3	. 600	. 0938	6. 40	−. 019	3. 32
4. 5	. 687	. 1041	6. 60	−. 027	4. 87
6	. 775	. 1186	6. 54	−. 012	6. 42
7. 5	. 858	. 1320	6. 50	−. 014	7. 96
9	. 935	. 1509	6. 20	−. 007	9. 50
12	1. 083	. 1885	5. 74	−. 026	12. 58
15	1. 228	. 2337	5. 25	−. 031	15. 66
18	1. 277	. 2986	4. 28	−. 062	18. 69
21	1. 242	. 3635	3. 42	−. 099	21. 67

TABLE XI

Sperry Messenger.
U. S. A. 27 wings.
Av. tank pres. = 20.5 atm.
Av. dynamic pres., q = 649 kg/m².
Av. Reynolds Number = 3,530,000.
Av. temperature = 37° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m².
Date, April 16, 1926.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−9	−0. 141	+0. 0534	−2. 64	+0. 037	−9. 08
−6	+. 032	. 0463	+. 69	. 017	−5. 98
−3	. 206	. 0465	4. 43	. 018	−2. 89
−1. 5	. 307	. 0501	6. 13	. 027	−1. 33
0	. 395	. 0555	7. 12	. 009	+. 21
+1. 5	. 489	. 0631	7. 75	. 005	1. 76
3	. 579	. 0719	8. 05	−. 005	3. 31
4. 5	. 674	. 0832	8. 10	+. 004	4. 86
6	. 755	. 0957	7. 89	−. 017	6. 41
7. 5	. 849	. 1099	7. 72	−. 010	7. 96
9	. 932	. 1266	7. 36	−. 022	9. 50
12	1. 099	. 1655	6. 64	−. 024	12. 59
15	1. 258	. 2121	5. 93	−. 049	15. 68
18	1. 401	. 2682	5. 22	−. 064	18. 76
21	1. 404	. 3509	4. 00	−. 086	21. 76
22. 5	1. 428	. 3891	3. 67	−. 122	23. 27

TABLE XII

Sperry Messenger.
Göttingen 387.
Av. tank pres. = 1 atm.
Av. dynamic pres., q = 28.5 kg/m².
Av. Reynolds Number = 172,000.
Av. temperature = 26° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m².
Date, May 28, 1926.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−9	−0. 021	+0. 0908	−0. 23	−0. 016	−9. 01
−6	+. 164	. 0764	+2. 15	+. 005	−5. 91
−3	. 339	. 0801	4. 23	−. 003	−2. 82
−1. 5	. 434	. 0859	5. 05	−. 019	−1. 27
0	. 529	. 0946	5. 59	. 022	+. 28
+1. 5	. 640	. 1062	6. 03	. 057	1. 83
3	. 724	. 1168	6. 20	. 033	3. 39
4. 5	. 815	. 1309	6. 22	. 046	4. 95
6	. 904	. 1436	6. 29	. 037	6. 49
7. 5	. 999	. 1641	6. 08	. 042	8. 04
9	1. 074	. 1815	5. 92	. 035	9. 58
10. 5	1. 142	. 2033	5. 62	. 010	11. 12
12	1. 216	. 2240	5. 43	. 012	12. 66
15	1. 352	. 2822	4. 79	. 005	15. 73
18	1. 416	. 3303	4. 28	−. 013	18. 76
21	1. 404	. 4040	3. 47	−. 050	21. 76

TABLE XIII

Sperry Messenger.
Göttingen 387 wings.
Av. tank pres. = 20.3 atm.
Av. dynamic pres. $q = 624$ kg/m^2.
Av. Reynolds Number = 3,400,000.
Av. temperature = 39° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m^2.
Date, May 10, 1926.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−9	+0. 041	+0. 0523	+0. 78	+0. 029	−8. 98
−6	. 228	. 0526	4. 33	. 019	−5. 88
−3	. 404	. 0609	6. 63	. 018	−2. 78
−1. 5	. 497	. 0685	7. 26	. 012	−1. 23
0	. 594	. 0778	7. 64	−. 002	+. 32
+1. 5	. 687	. 0891	7. 71	−. 006	1. 87
3	. 772	. 1010	7. 64	−. 017	3. 42
4. 5	. 865	. 1176	7. 36	−. 023	4. 97
6	. 957	. 1337	7. 16	−. 044	6. 52
7. 5	1. 041	. 1521	6. 84	−. 050	8. 06
9	1. 124	. 1735	6. 47	−. 059	9. 61
12	1. 282	. 2185	5. 87	−. 096	12. 69
15	1. 362	. 2856	4. 77	−. 182	15. 73
18	1. 350	. 3593	3. 76	−. 227	18. 73

TABLE XIV

Sperry Messenger.
R. A. F. 15 wings.
Av. tank pres. = 1 atm.
Av. dynamic pres., $q = 27.0$ kg/m^2.
Av. Reynolds Number = 160,000.
Av. temperature = 53° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m^2.
Date, June 15, 1926.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−9	−0. 281	+0. 1003	−2. 80	−0. 036	−9. 15
−6	−. 110	. 0700	−1. 57	−. 004	−6. 06
−3	+. 076	. 0607	+1. 25	+. 018	−2. 96
−1. 5	. 176	. 0618	2. 85	. 004	−1. 41
0	. 273	. 0637	4. 28	−. 017	+. 15
+1. 5	. 360	. 0691	5. 21	−. 026	1. 69
3	. 446	. 0788	5. 66	−. 021	3. 24
4. 5	. 543	. 0867	6. 26	−. 044	4. 79
6	. 626	. 0991	6. 32	−. 064	6. 34
7. 5	. 714	. 1117	6. 39	−. 066	7. 88
9	. 794	. 1278	6. 21	−. 109	9. 43
12	. 945	. 1662	5. 68	−. 116	12. 51
15	1. 044	. 2530	4. 13	−. 156	15. 56
18	1. 051	. 3523	2. 98	−. 105	18. 57
21	1. 010	. 4643	2. 18	−. 145	21. 54

TABLE XV

Sperry Messenger.
R. A. F. 15 wings.
Av. tank pres. = 20.2 atm.
Av. dynamic pres., q = 600 kg/m^2.
Av. Reynolds Number = 3,220,000.
Av. temperature = 47° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m^2.
Date, June 15, 1926.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−6	−0. 078	+0. 0445	−1. 75	−0. 006	−6. 04
−3	+. 096	. 0399	+2. 41	−. 007	−2. 95
−1. 5	. 187	. 0411	4. 55	−. 013	−1. 40
0	. 286	. 0449	6. 37	−. 008	+. 15
+1. 5	. 381	. 0508	7. 50	−. 018	1. 71
3	. 470	. 0577	8. 15	−. 024	3. 25
4. 5	. 572	. 0683	8. 38	−. 024	4. 81
6	. 662	. 0798	8. 29	−. 022	6. 36
7. 5	. 751	. 0925	8. 12	−. 032	7. 91
9	. 838	. 1079	7. 77	−. 034	9. 45
12	1. 007	. 1478	6. 82	−. 058	12. 54
15	1. 146	. 2071	5. 53	−. 072	15. 62
18	1. 151	. 2573	4. 47	−. 110	18. 62
21	1. 135	. 3545	3. 20	−. 051	21. 61

TABLE XVI

Sperry Messenger.
Clark Y wings.
Av. tank pres. = 1 atm.
Av. dynamic pres., q = 28.0 kg/m^2.
Av. Reynolds Number = 169,000.
Av. temperature = 27° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m^2.
Date, June 11, 1926.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−9	−0. 054	+0. 0710	−0. 76	−0. 035	−9. 03
−6	+. 105	. 0657	1. 60	−. 009	−5. 94
−3	. 289	. 0682	4. 24	−. 036	−2. 84
−1. 5	. 392	. 0730	5. 37	−. 038	−1. 29
0	. 477	. 0815	5. 86	−. 037	+. 26
+1. 5	. 578	. 0910	6. 35	−. 037	1. 81
3	. 668	. 1029	6. 49	−. 027	3. 36
4. 5	. 740	. 1138	6. 50	−. 041	4. 90
6	. 836	. 1293	6. 46	−. 020	6. 45
7. 5	. 916	. 1454	6. 30	−. 030	7. 99
9	. 983	. 1641	5. 99	−. 002	9. 53
12	1. 142	. 2070	5. 52	−. 088	12. 62
15	1. 226	. 2597	4. 72	−. 140	15. 66
18	1. 172	. 3530	3. 32	−. 179	18. 63
21	1. 086	. 4593	2. 36	−. 111	21. 58

TABLE XVII

Sperry Messenger.
Clark Y wings.
Av. tank pres. = 20 atm.
Av. dynamic pres., $q=623$ kg/m².
Av. Reynolds Number = 3,350,000.
Av. temperature = 42° C.

Span = 24 in. (61.0 cm).
Chord = 4.8 in. (12.2 cm).
Aspect ratio = 5.
Area = 0.1377 m².
Date, June 11, 1926.

Angle of attack, degrees α	Lift coefficient C_L	Corrected C_D	L/D	Moment coefficient C_M	Corrected angle of attack, degrees
−9	−0. 088	+0. 0465	−1. 89	−0. 017	−9. 05
−6	+. 103	. 0431	2. 39	+. 001	−5. 94
−3	. 280	. 0481	5. 82	−. 001	−2. 85
−1. 5	. 375	. 0528	7. 10	−. 002	−1. 30
0	. 474	. 0608	7. 79	−. 012	+. 26
+1. 5	. 566	. 0703	8. 05	−. 017	1. 81
3	. 647	. 0797	8. 12	−. 015	3. 35
4. 5	. 744	. 0937	7. 94	−. 023	4. 90
6	. 835	. 1091	7. 66	−. 026	6. 45
7. 5	. 925	. 1259	7. 35	−. 035	8. 00
9	1. 009	. 1438	7. 02	−. 030	9. 54
12	1. 177	. 1884	6. 25	−. 054	12. 63
15	1. 328	. 2400	5. 54	−. 068	15. 72
18	1. 450	. 2974	4. 87	−. 088	18. 78
21	1. 344	. 4030	3. 33	−. 144	21. 73

TABLE XVIII

SUMMARY OF DATA

Airfoil section	Tank pressure in atmospheres	Reynolds Number	C_L max.	C_D min.	Ratio $\frac{C_L \text{ max.}}{C_D \text{ min.}}$	Max. L/D
U. S. A. 5 without propeller	1	173, 000	1. 194	0. 0702	16. 7	6. 61
	20. 3	3, 390, 000	1. 279	. 0476	26. 9	8. 28
U. S. A. 35-B	1	177, 000	1. 220	. 0689	17. 7	6. 55
	20. 2	3, 410, 000	1. 490	. 0440	33. 8	8. 26
U. S. A. 27	1	175, 000	1. 277	. 0706	18. 1	6. 60
	20. 5	3, 530, 000	1. 428	. 0460	31. 0	8. 10
Göttingen 387	1	172, 000	1. 416	. 0764	18. 5	6. 29
	20. 3	3, 400, 000	1. 362	. 0515	26. 4	7. 71
R. A. F. 15	1	160, 000	1. 051	. 0607	17. 3	6. 39
	20. 2	3, 220, 000	1. 151	. 0399	28. 8	8. 38
Clark Y	1	169, 000	1. 226	. 0657	18. 7	6. 50
	20. 2	3, 350, 000	1. 450	. 0431	32. 9	8. 12

TABLE XIX

ORDER OF MERIT OF AIRFOILS

Order of merit	From Sperry Messenger tests			
	C_L max. / C_D min.		Max. L/D	
	1 atm.	20 atm.	1 atm.	20 atm.
1	Clark Y	U. S. A. 35-B	U S. A. 5	R. A. F. 15.
2	Gött. 387	Clark Y	U. S. A. 27	U. S. A. 5.
3	U. S. A. 27	U. S. A. 27	U. S. A. 35-B	U. S. A. 35-B.
4	U. S. A. 35-B	R. A. F. 15	Clark Y	Clark Y.
5	R. A. F. 15	U. S. A. 5	Gött. 387	U. S. A. 27.
6	U. S. A. 5	Gött. 387	R. A. F. 15	Gött. 387.

Order of merit	From airfoil tests			
	C_L max./ C_D min.,		Max. L/D	
	1 atm.	20 atm.	1 atm.	20 atm.
1	R. A. F. 15	U. S. A. 35-B	Clark Y	R. A. F. 15.
2	Clark Y	R. A. F. 15	U. S. A. 5	U. S. A. 5.
3	U. S. A. 5	Clark Y	R. A. F. 15	Clark Y.
4	U. S. A. 27	U. S. A. 27	U. S. A. 27	U. S. A. 27.
5	U. S. A. 35-B	Gött. 387	U. S. A. 35-B	U. S. A. 35-B.
6	Gött. 387	U. S. A. 5	Gött. 387	Gött. 387.

TABLE XX

ORDINATES OF SECTIONS

Per cent chord	U. S. A. 5		U. S. A. 35-B		U. S. A. 27	
	Upper	Lower	Upper	Lower	Upper	Lower
0	0. 73	0. 33	2. 76	2. 76	1. 77	1. 77
1. 25	2. 10	. 17	5. 15	1. 03	3. 80	. 50
2. 5	3. 03	. 03	6. 10	. 61	5. 07	. 33
5	4. 40	. 03	7. 53	. 27	6. 93	. 17
7. 5	5. 40	. 25	8. 65	. 14	8. 22	. 10
10	6. 20	. 57	9. 47	. 07	9. 17	. 00
15	7. 16	1. 10	10. 57	. 00	10. 50	. 10
20	7. 92	1. 55	11. 28	. 05	11. 33	. 35
30	8. 30	2. 02	11. 74	. 16	11. 90	. 95
40	8. 14	2. 17	11. 37	. 28	11. 57	1. 17
50	7. 55	1. 96	10. 29	. 41	10. 77	. 80
60	6. 75	1. 55	8. 86	. 41	9. 52	. 25
70	5. 63	1. 16	7. 08	. 41	8. 00	. 10
80	4. 24	. 76	5. 02	. 37	6. 03	. 05
90	2. 52	. 55	2. 76	. 21	3. 65	. 15
95	1. 50	. 35	1. 52	. 12	2. 00	. 47
100	. 50	. 00	. 28	. 00	. 67	. 65

Per cent chord	Gött. 387		R. A. F. 15		Clark Y	
	Upper	Lower	Upper	Lower	Upper	Lower
0	3. 61	3. 61	0. 20	0. 20	3. 50	3. 50
1. 25	6. 74	1. 35	1. 90	−. 45	5. 45	1. 93
2. 5	7. 98	. 81	2. 80	−. 73	6. 50	1. 47
5	9. 87	. 36	3. 90	−. 90	7. 90	. 93
7. 5	11. 32	. 18	4. 60	−1. 00	8. 85	. 63
10	12. 40	. 13	5. 05	−1. 00	9. 60	. 42
15	13. 83	. 00	5. 58	−. 80	10. 69	. 15
20	14. 77	. 08	5. 76	−. 50	11. 36	. 03
30	15. 36	. 22	5. 80	−. 10	11. 70	. 00
40	14. 88	. 38	5. 58	−. 05	11. 40	. 00
50	13. 48	. 54	5. 17	−. 28	10. 52	. 00
60	11. 59	. 54	4. 68	−. 47	9. 15	. 00
70	9. 16	. 54	4. 07	−. 62	7. 35	. 00
80	6. 58	. 50	3. 28	−. 67	5. 22	. 00
90	3. 61	. 27	2. 24	−. 35	2. 80	. 00
95	1. 99	. 16	1. 63	−. 20	1. 49	. 00
100	. 37	. 00	. 30	+. 30	. 12	. 00

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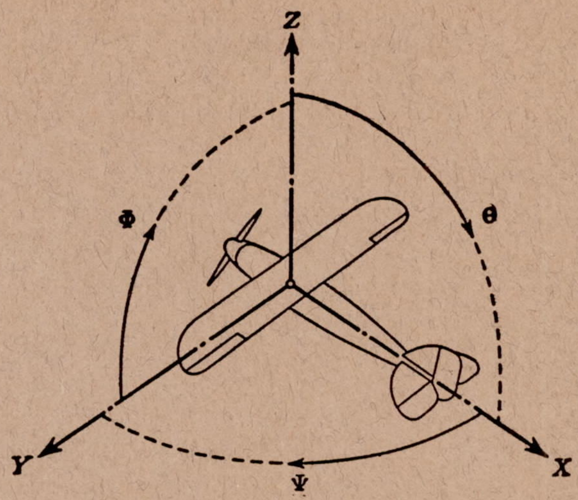

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L=\frac{L}{qbS}\quad C_M=\frac{M}{qcS}\quad C_N=\frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $= T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute., R. P. M.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 HP = 76.04 kg/m/sec. = 550 lb./ft./sec.
1 kg/m/sec. = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft